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SHADOWING OF X-RAYS BY THE INTELLAR CLOUDS IN OPHIUCHUS AND X-RAY SHADOWING OBSERVATIONS OF A MOLECULAR CLOUD BEHIND THE LOCAL HOT BUBBLE

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Annual Report for NAG5-2473: "Shadowing of X-rays by the Interstellar Clouds in Ophiuchus" and "X-ray Shadowing Observations of a Molecular Cloud Behind the Local Hot Bubble"

Synopsis

This grant supported analysis of observations of two interstellar cloud complexes with the ROSAT PSPC during AO4. The cloud complexes, Ophiuchus and G337+4, are located at different distances toward the general direction of the Galactic center, where the soft X-ray background is brightest. From the observations of shadowing of the soft X-ray background by the complexes, we planned to derive information about the otherwise unknown source distribution for the background and to quantitatively study the column densities of molecular gas in the complexes. The reduced data represent some of the largest fields of mosaicked PSPC observations. The shadowing is clear toward each complex, although deriving quantitative results for the properties of the shadowing clouds is proving to be more problematic than expected.

Research Description

The existence of a pervasive X-ray background has been known since the 1960s. At higher energies, the observed isotropy indicates that the background is extragalactic. (Recently, deep observations with the PSPC were used by Hasinger et al. (1993) to resolve a large fraction of this background.) At soft X-ray energies, hot, diffuse gas in the Galaxy is a source, and the extended X-ray emission is brightest toward the inner Galaxy. The relative contributions of the so-called Local Hot Bubble and the hot gas in the Galactic halo to the soft X-ray background have not been established before.

At soft X-ray energies, most of the absorption of the interstellar medium is due to trace species, the elements heavier than helium, in gas and dust. The dust is generally assumed to be mixed with the gas, which consists largely of atomic and molecular hydrogen (with a significant admixture of helium). H I can be observed directly in the 21-cm line of the hyperfine transition. H_2 does not have a radio spectrum and is not generally directly detectable in interstellar space. The most commonly used tracer for molecular hydrogen is the $J = 1–0$ line of CO at 115 GHz. CO is the second most abundant molecule after H_2 and conditions favorable for the formation of one are favorable for the other. The lowest rotational transition of CO is excited at the temperatures and densities prevalent in molecular clouds. Observational evidence has long suggested that along a given line of sight the column density of molecular gas $N(H_2)$ is proportional to the integrated intensity W_{CO} of the CO line. The calibration of the proportionality requires another indirect tracer of column density. Soft X-ray absorption is potentially such a tracer, as early observations of shadowing by Burrows & Mendenhall (1991) with ROSAT suggested. We planned to derive the proportionality in the two complexes we observed.

The interstellar clouds in Ophiuchus are about 125 pc distant, approximately in the center of the Local Hot Bubble, and G337+4 is about 2 kpc distant, beyond the far side of the bubble. Most of the X-ray emission from the bubble is from the shocked gas near the edges, so the X-ray intensity foreground to Ophiuchus represents the emission of the near side of the Local Hot Bubble.

For both observing programs, the extents of the regions of interest were large enough that multiple short observations with the PSPC were required. S. Snowden, a co-investigator in this research, developed the techniques for mosaicking the observations, including background subtraction, point source removal, and relative gain corrections. These techniques were applied to the observations of Ophiuchus and G337+4. Each of the 25 Ophiuchus PSPC fields and 14 G337+4 fields was processed in this way, and yielded maps with effective resolution of about 15' at 3/4 keV (Figure 1).

Shadowing is evident toward both Ophiuchus and G337+4 in Figure 1, with a fairly detailed correspondence with CO emission apparent. For G337+4, only low-resolution, low sensitivity CO observations existed and a special survey of this complex was undertaken by L. Bronfman (1995, private communication) to match the coverage and effective resolution of the PSPC observations. The background X-ray intensity toward Ophiuchus is much brighter than toward G337+4, but a distant, i.e., Galactic, component of the soft X-ray background is clearly indicated for the first time.

The drawbacks to the quantitative analysis of the clouds, i.e., to the determination of molecular column densities, are unfortunately several. Column densities in the central parts of the clouds are great enough that the optical depths are not small, so the clumping of the gas on small scales is important. The spectral bands of the PSPC are broad, the absorption cross sections strongly energy dependent, and the abundances of the trace species are not known accurately, so the relation between optical depth and column density is somewhat uncertain. In addition, the soft X-ray background cannot be assumed to be uniform on the several-degree scales of the clouds, complicating models of the shadowing. In Ophiuchus in particular, the correlation of the shadowing with N(H I), which dominates the total column densities in the periphery of the cloud complex, is particular poor.

On-going Research

We are investigating the spectral and intensity differences of the X-ray background toward the nearby Ophiuchus and distant G337+4 cloud complexes. We are also investigating several approaches that may help overcome the drawbacks discussed above. If only the highest energy PSPC band is used, the cross sections may be small enough for the clouds to be optically thin, and the tradeoff of lower effective resolution owing to the fewer photons at higher energies may be acceptable. In the event this is not successful, we expect to apply the $N(H_2)/W_{CO}$ ratio derived from an analysis of the diffuse gamma-ray emission in Ophiuchus by Hunter et al. (1994) in order to at least be able to quantify the effects of clumping on small scales. We are investigating the lack of correlation of shadowing with H I in the Ophiuchus observations by considering H I on separate line-of-sight velocity ranges to try to distinguish foreground and background column densities.

Publication

"The X-ray Shadow of the Ophiuchus Dark Clouds," S. L. Snowden, S. W. Digel, and M. J. Freyberg, Napa Valley HEAD AAS meeting, October, 1994

Figure 1. X-ray intensity in the 3/4 keV (PSPC R4 + R5) band with overlays of CO intensity. (*a*) Ophiuchus; CO map from de Geus, Bronfman, & Thaddeus (1990). X-ray count rate: 0–670 x 10^{-6} s^{-1} $arcmin^{-2}$; W_{CO} contours 6 x 6 K km s^{-1}. (*b*) G337+4; CO map from a special survey by L. Bronfman (1995, private communication). X-ray count rate: 0–380 x 10^{-6} s^{-1} $arcmin^{-2}$; W_{CO} contours 1.8 x 1.8 K km s^{-1}. The X-ray and CO maps have resolutions ~15'.